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Department of Industrial Engineering and Management
RVCE

Operations Research (18G5B09)- Global Elective

Experiential Learning

Game Theory Applications

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18G5B09 – OPERATIONS RESEARCH

EXPERIENTIAL LEARNING

(Game Theory Applications)

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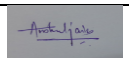
1	1RV19AS007	Anshul Jain	
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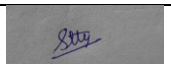
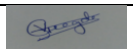
3	1RV19ME005	Abhishek Shetty	
4	1RV19ME118	Venkatanarasimha G Hedge	

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Abstract

A military deal is of great importance to any nation's security and safety. In choosing an option in a military deal, there is careful consideration over the impact of the decision, in a holistic manner. This includes the timeline, the financial impact, the effectiveness, etc. This report serves to build a simplified game matrix, to aid in decision making in a military deal. This has further been supported using other Operations Research techniques. The example of the Naval fighter deal floated by the Indian Navy has been considered, in order to bring in real-world parameters, while also allowing for the flexibility of assumptions, to aid in building a model that can be furthered and replicated for other such military decision-making exercises.

Introduction

The Indian Navy is the naval branch of the Indian Armed Forces and is the 7th largest in the world. It operates in the Indian peninsula, guarding the large maritime border of India. Due to regional adversaries, as well as the sheer size of the border it guards, there is a need for a large fleet of both naval vessels, as well as supporting aircraft.

In order to fulfill its ever-growing need for support aircraft for aircraft carriers, the Indian Navy, in 2018, floated an RFI for the sale of 57 fighter aircraft. Two defence majors, Boeing and Dassault, responded to the RFI, by pitching F/A-18E Super Hornet, and the Rafale (Naval version) respectively. This deal, however, was subsequently junked due to changing needs, the necessity of local manufacturing, etc.

We are hence presented with an opportunity to make an unbiased review of the same deal, and arrive at an outcome, by making reasonable assumptions, using existing information. An attempt has been made to present our findings in a manner that makes it easy for the methodology to be implemented on other such applications within the military space.

F/A-18E Super Hornet is an American 4th generation multirole aircraft designed by Boeing, based on the McDonnell Douglas F-18 Hornet. It is very widely used by the US Navy, alongside Australian and Kuwaiti Air Forces. It is also being considered by many other potential operators, including Finland, Germany, Spain, and India.

The Dassault Rafale is a French 4.5 generation multirole aircraft, designed by Dassault Aviation. It is used primarily by France, Qatar, and India's Air forces, while also being looked at by other countries.

Problem Statement

Analysis of the Indian Navy fighter aircraft deal for Dassault Rafale-M and Boeing F/A-18E Super Hornet based on technical superiority, cost, and other factors for best decision and least cost in long term, using Game Theory and other Operations Research techniques.

Literature Review

Game theory has become a conventional decision-making methodology in economics, social sciences, finance, population dynamics, and epidemics. There are always optimal strategies in the context of complex interactions between two or more parties and give us some form of

predictions beforehand. But game theory is predominant in the fields of defense, both for resource procurement and negotiations as well as for strategic planning and control. This review is solely focused on resource allocation warfare sub-domain in the military and all the relevant game theory applications with respect to it are discussed here. Before studying the application, a review on different types of games seems necessary and is as follows,

Military's Main Method	Command and Control Warfare				
Period	Traditional (T)			Modern (M)	
Military Field	Land (L)	Air (A)	Sea (S)	Cyber (C)	Space (S)
Major Military Field	Resource Allocation Warfare (RAW) or Information Warfare (IW) or Weapon Control Warfare (WCW) or Adversary Monitoring Warfare (AMW)				
Game Theory Category 1	Non-Cooperative (NCo) or Cooperative (Co)				
Game Theory Category 2	Sequential (Seq) or Simultaneous (Sim)				
Game Theory Category 3	Discrete (D) or Continuous (C)				
Game Theory Category 4	Zero Sum (ZS) or Non-Zero Sum (NZS)				

Fig. 1- Allocation of warfare

In warfare the decisions regarding the utilized resources are too made well before the engagement and assumptions on strength of different elements in the arsenal are necessary, that is they must be able to weigh their own as well as enemy capabilities for deciding suitable strategies. However, because of confidentiality in the military field, not much literature is available. Hamilton et al gives a comprehensive approach to aerial warfare. First determination of all the tactical options left to each side is to be determined. This involves understanding how much value each asset and item in inventory holds and checking the possibilities of these to be used in strategic actions. To each of these assign a value called measure of effectiveness (MoE). Next, calculate the combined value of all the possible interactions between the strategies of two players. This gives the payoff matrix which can be used to get the Nash equilibrium or the value of the game. One important point to be highlighted in his proposal is that the length of time of warfare should be taken as expected total time of warfare as the whole and not length of individual tasks involved separately.

Deligiannis et al. made his proposal for power allocation in the MIMO radar network under the influence of multiple jammers. The objective of minimization of total power emitted while still being detected by specific targets. Radar operators and jammer operators both are said to be intelligent and can adjust the power accordingly to maximize interference to radar. This is a non-cooperative game of two players. This problem is solved using convex optimization techniques.

Garcia et al. formulates a zero sum game where the defender tries to capture attackers. It is assumed that the attackers get caught and hence the winner tries to minimize the distance between each other. The payoff matrix is in the form of distances between the attackers and defenders and the solution gives the optimal distances between each.

He et al. made several changes to the Radar power allocation problem. The problem was made to minimize total transmitted power and mitigate the interferences. Another variable of jammer effect on transmission was introduced. First, they study the power allocation game with strategies of each player being the power allocated; pay-off matrix consists of the number of targets that faithfully receive the transmission for one whereas for the other player it is the number of transmission jammed. This non-cooperative non zero-sum game was observed to have a unique Nash equilibrium.

Further the study was done on the process flow in aircraft maintenance. The basic

processes involving in the maintenance were noted and their values are taken based on the respective dealers i.e. Rafael and Boeing. The basic parameters listed were related to their basic process flow involved during their maintenance and production of an aircraft. The three time estimates method can be used to estimate the critical process path. The PERT analysis involved in maintenance provides the duration which would help them take easily the best strategy for their deal to gain maximum profit out of the deal.

Also this data relates their expenditure spent on a yearly basis and provides them the effect of their decision in the long term scenario.

Methodology

The procurement of arms and equipment is decided based on various factors ranging from arms capabilities to international relations. In respect to the fighter craft procurement, the key performance features are - life cycle costs, operating costs, power, range, weapons load, ruggedisation, electronic sophistication, survivability in addition to the political advantages and the transfer of absorbable technology. Many of the factors that dominate the decision-making process cannot really be modelled into numerical models and is the major challenge of this problem. Another issue in creating a payoff creating a payoff matrix for the given problem is confidentiality of resources and prior decisions involved. Hence, some methods to approximate the amounts involved are done. Literature completely unrelated to competition between two companies is used to deduce a methodology to solve the problem.

The given problem has cost as the major factor. India being a developing country cannot have a major portion of the military budget on aircrafts. There are around 5 important factors that dominate the decision making process and include,

- Aircraft cost
- Superiority
- Maintenance time and cost
- Involvement of other countries
- Knowledge of the technology in enemy countries

The cost of one unit of Rafale fighter jet is around 78.63 million US dollars for a basic model without advanced maneuverability, superior electronics, shorter range and lesser weapon carrying capacity. Although the actual costs were not available. We used the data from 2006 and used the inflation rate to determine the current value. An improved or advanced model for the same costs 134.6 million dollars. The competitor Boeing F-18 has multiple models. Among these, one with least cost and features is chosen as the basic model and the one with higher cost and most of the extra attachments is used as the advanced model for determination of payoff matrix. There are two options for India either to manufacture the aircraft in India or to manufacture it off-country in France or US for Rafale and F-18 respectively. The locally made aircrafts come at an extra cost of resource transfer of companies from a foreign country to India. whereas, foreign-made comes at the cost of increased taxation of foreign countries, restrictions and transportation costs. Using the shipping cost, tax values etc. information of US and France extra cost is calculated to be 45440 million dollars. local manufacture comes at an extra cost of 32320 million dollars (referring to some other companies expenditure). Thus the total cost factor involved can be said to be the ratio of total cost involved to military expenditure. There is a demand of 126 aircraft from India.

Consider Rafael aircraft of basic utilities and produced locally in India. The cost factor involved is 0.4133. Similarly we have the superiority of aircraft variables involved. Expressing this in a numerical value is done by using the ratio of number of superiority that Rafael or F-18 satisfy in comparison to previous models used in India (Tejas). There are 12 superiority factors involved and are:

- Power
- Range
- Weapons load
- Ruggedisation
- Electronics
- Avionics
- Survivability
- Manoeuvrability
- Thrust
- Speed
- Climb rate
- Operating cost

If the power requirement is lesser than the previous models used in India, Rafael is said to have one superiority. By search, we found that the basic Rafale satisfies 5 of these and the advanced model satisfies 7 of these.

Boeing however, has 7 superiorities over previous models in basic model and 9 superiorities over previous models in advanced model. These numbers divided by the total numbers of factors considered gives us the superiority factor which is another payoff component along with cost factor.

Maintenance time and cost are assumed to have linear proportionality. Considering similar maintenance operations, a network model is created that is common to both Boeing and Rafael, but the times for these are little different. Although no information on these were available, referring to some previous models of aircraft, approximate duration of maintenance was calculated. According to our studies, we found out that the maintenance cost did not play much in the decision-making. International relations had predominance in decision-making in the Indian military. Countries involved directly or indirectly are the US, China, Russia and France. Thus, France and US pressurise India not to buy Boeing and Rafael respectively. Whereas endorsing their native aircraft. Also countries like Russia although not directly involved does not want India to make a deal with the US and opposes it. Thus another factor was introduced to payoff. incase of support one was added, in case of opposition value one was subtracted and this value was divided by the number of countries involved. Finally through research it was concluded that none of the neighbouring countries have Rafael or F-18 and they do not have the dedicated countermeasure for it. This eliminates the effect of inclusion of technology. Adding all the factors together gives the values for Boeing and Rafael separately. The difference between the two gives the payoff matrix.

	A	B	C	D	E	F	G
1	Nodes	Activity	Discription	Precence Activity	optimistic time	Pessimistic time	Mean time
2	1-2	A	Check stand by pump	-	28	36	32
3	2-3	B	Calibrate all ganges	A	72	88	80
4	2-4	C	Dismantle pump cover and remove rotor	A	6	10	8
5	2-5	D	Dismantle turbine cover andre move	A	12	20	16
6	3-6	E	Clean all ganges and line	B	28	36	32
7	6-18	F	Replace ganges	E	12	20	16
8	4-7	G	Repair lubrication system	C	28	40	34
9	4-8	H	rebuld impeller	C	256	352	304
10	4-11	I	Clean pump casting	C	24	36	31
11	7-11	J	Fix pump bearings	G	12	20	16
12	8-11	K	Balance Impeller	H	28	36	32
13	11-14	L	Reinstall Impeller	I,J,K	12	20	16
14	5-9	M	Rebuild turbine rotor	D	260	400	335
15	5-10	N	Check trubine bearings	D	10	18	15
16	9-12	O	Balance turbine rotor	M	56	72	64
17	10-12	P	Fix trubine bearings	N	12	20	16
18	12-13	Q	Fix turbine rotor	O,P	16	28	22
19	13-15	R	Fix turbine cover	Q	20	32	26
20	15-18	S	Test components	R	12	18	15
21	15-18	T	Check clearance	R	14	18	16
22	14-16	U	Fix pump bearings	L	12	20	16
23	16-17	V	Fix pump cover	U	18	24	21
24	17-18	W	Install shaft packing	V	14	18	16
25	18-19	X	Final test	S,T,W,F	48	72	60

Fig. 2-Network data for aircraft manufacture for PERT for Rafael

Fig. 3 - Input in TORA

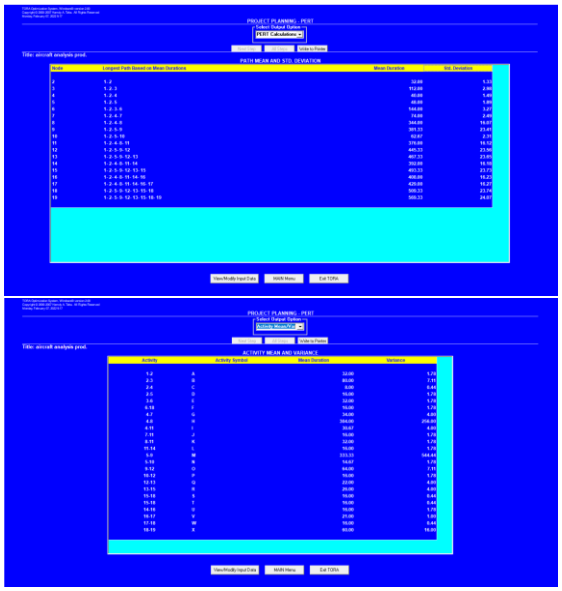

Fig. 4 - Critical path for Rafael

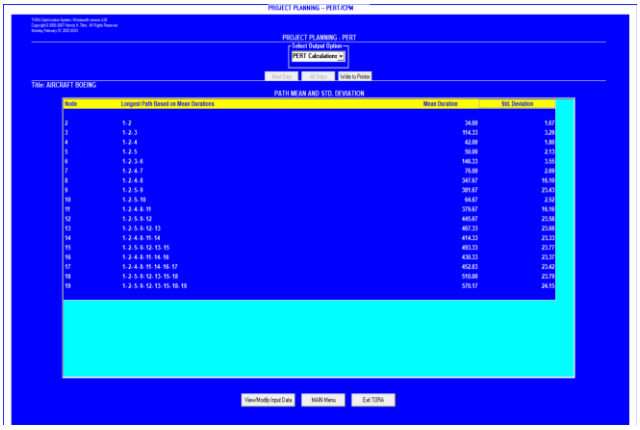

Fig. 5 - Critical path for Boeing

The duration for the aircraft maintenance process is 569.33 hours (1-2-5-9-12-13-15-18-19) for Rafael and for Boeing is 572.71 hours (1-2-5-9-12–13-15-18-19). Thus can be seen that the maintenance quality and speed of Rafael is more than that of Boeing.

Now since the idea is to implement the decision based on various factors mentioned above, the game matrix formation is based considering the above all parameters.

The payoff matrix is based on considering the strategies like-

- L+A
- L+B
- F+A
- F+B

where L- Local, B- Basic design not including extra features like sensors, etc., F-Foreign, A- Advanced design with all extra facilities included.

Here Player A is Rafael and Player B is Boeing

Calculation of Payoff Matrix

For Player A,

L+B calculation,

Net outcome=cost factor + superiority + international relation factor (i.e. foreign supply)

Net outcome=$1-\frac{127*78624826+32320000000}{63000000000}+\frac{5}{12}-\frac{1}{3}$

=0.4132

Similarly for Player B,

Net outcome =0.2276

Therefore the net payoff value for L+B is 0.4132-0.2276=0.1857

Similarly all other values are evaluated based on the same logic.

Player A \ Player B	L+B	L+A	F+B	F+A
L+B	18.57	1.83	39.35	14.43
L+A	34.24	19.5	55	30.1
F+B	2.36	-19.1	18.42	-0.5
F+A	20.24	3.5	41	16.1

Fig. 6 - Payoff Matrix (All values **x100)**

1. Saddle point testing
Players

Player B

Player A	B_1	B_2	B_3	B_4
A_1	18	1	39	14
A_2	34	19	55	30
A_3	2	-19	18	0
A_4	20	3	41	16

We apply the maximin (minimax) principle to analyze the game.

Player B

Player A	B_1	B_2	B_3	B_4	Row Minimum
A_1	18	1	39	14	1
A_2	34	[(19)]	55	30	[19]
A_3	2	-19	18	0	-19
A_4	20	3	41	16	3
Column Maximum	34	(19)	55	30	

Select minimum from the maximum of columns
Column MiniMax = (19)

Select maximum from the minimum of rows
Row MaxiMin = [19]

Fig. 7 - Game matrix solution from calculator

The value of the game comes out to be 0.2 which implies that there is a win to Rafael and a loss of Boeing. The strategies which are best suited for both are L+A.

Tools Used

1. PERT
2. Two-player Zero-Sum game
3. TORA
4. atozmath.com

Here TORA is used for PERT analysis and to find output of the payoff matrix, an atozmath online calculator is used.

Results and Discussions

The value of the game indicates the game has a saddle point at second strategy i.e. L+A, which is best for both. The cost

analysis according to their current budget shows that the deal is feasible for them and will surely make profit in their way. The analysis with help of PERT and game theory help to identify the backup plan for both of them to optimize their decision so that their company will not face any issues regarding the deal in future. It also gives a probable indication to both the dealers (Boeing and Rafael) about the overhead cost and risk involved in this deal and provides the best strategy.

While the scope of this project has remained analyzing the aforementioned deal, it also serves as a basic idea, on which the concept of application of game theory to military deals can be expanded upon. Game theory has many applications, and in choosing to apply it to military deals like the Indian Navy deal, we have looked to address a gap in the existing literature in the public domain.

This has vast potential for individuals or organizations or governments looking to analyze military deals of the past or the future.

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